Proceedings of the Iowa Academy of Science

Volume 46 | Annual Issue Article 8

1939

The Philosophy of Science

H. T. Davis
Northwestern University

THE PHILOSOPHY OF SCIENCE

H. T. Davis

A few months ago I sat at a banquet in a room of mirrors. The group of guests communicated with one another by spoken words. But as I sat and looked down the corridor of reflected images of ourselves, I could not help but feel that a vision of the great past of the human race was presented to my eye. As far as one could see, a vast assemblage of human forms was visible and I felt that in this little instant of the present time we were accompanied by the shadows of all those who had lived before us. There in a distant image I caught a glimpse of the lofty figures of the Athenean school, Aristotle walking among the olive trees; Hippocrates, probing into the cause of human ills from which he formulated an oath that in later times was to be adopted as one of the most idealistic principles of the race. A little nearer we view the scholars of the great University of Alexandria. There is Euclid reflecting upon the theorems in his immortal "Elements." We see also the image of Aristarchus, measuring the distance to the sun and moon, and Aratosthenes, centuries ahead of his times, proving that the earth is spherical and measuring its diameter. And there is Archimedes laying the foundations of mechanics, and Hero with his steam engine, and Ptolemy reflecting upon the mystery of the planets. A little nearer our own times we see the mystic figure of Galileo, defying the prejudice of his age and proving that the earth is but a moving atom in a universe of unimaginable magnitude. And there is Newton penning the immortal passages of his "Principia." And there also are Faraday and Maxwell, Wallace and Darwin, Koch and Pasteur, Lamarck and Werner, and all the other immortals who by their careful studies and brilliant generalizations were to found that thing which we have called by the simple name of Science.

And then I turned toward the other wall of mirrors and again I saw another vast assemblage of human beings stretching far into the future. There in epitome was the future of the human race. And there, could we but recognize them, were another Euclid and another Newton and another Pasteur, who would find things about which we now only vaguely dream, and who would assert principles of supreme importance to the race.

And as I reflected upon these matters a page in uniform crossed the room and there I saw a great column of marching men, whose shadow obscured some of the faces that I have mentioned. And it occurred to me that a great human problem was involved also in the development of science. Science, objective, mathematical, idealistic in the highest meaning of that word, is not a thing apart from the mechanism of human actions and human hopes and human fears. A philosophy of science must be created, which will state the ultimate objectives of these men whom I have mentioned and act as a star toward which we in the present time may go, and which will guide those future colleagues of ours who are at present only images.

Science to the great mass of people is mysterious and terrifying. To prove this one needs but follow its slow development and witness even in our own day the many prejudices that hamper progress. The masses, having little knowledge of the history of science and of past states of social development, but dimly know that the present high level of human living is due in major part to the conquests of science. But when there is a decline in present standards, then science is at fault and must be blamed. By this I mean to say that science is something of an aristocratic domain and that many cannot enter its portals. Its laws and principles cannot at present and perhaps never can be stated in a form that will be appreciated by all the people. Therefore, it is an important matter for us as the high priests in the temple to pause a moment from the specific problems of the laboratory and to formulate the principles upon which we work. This formulation is what I shall call the philosophy of science.

I shall therefore discuss with you a few of the principles which have appealed to me as being among our most cherished ones. No man can approach this problem of formulation with out prejudice, since he has channels of interest which direct his thinking. After a training mainly devoted to mathematics and physics, I have more recently turned to one of the most intriguing lines of recent speculation. This is the study of human actions as they relate to economics. My views are thus highly colored by this sudden shock of attempting to apply the rigid principles of physics, and the cold logic of mathematics, to the erratic and mysterious behavior of human beings. Hence my formulation of the philosophy of science may not agree in all, or even in large part, with that of many of you.

Let us start with the first principle, which we may call the *principle of logic.* This is the cardinal principle of mathematics. It assumes that there exists a process, external to the forms of the world and to the will of man, which leads from a set of postulates to a set of conclusions. These conclusions are inevitable and irrefrangible. God himself cannot change them. It is for this reason that the phrase "mathematically proved" has come to have such conclusive and complete finality.

In recent years there has been some rescrutiny of the principle, and we shall take a moment to indicate some examples. Thus, all of you were probably taught in school that the sum of the angles of a triangle is equal to 180 degrees. One did not need to take this on the instructor's authority, since there was a logical proof of the proposition. But now it is gradually coming into common knowledge that this theorem is not true, if we give a somewhat liberal definition to the word true. On the other hand, it is not false. The sum of the angles of a triangle may be either greater than 180 degrees, equal to 180 degrees, or less than 180 degrees entirely according to how one may feel about the matter. Gauss, who was among those first to observe this strange situation, was so impressed by the matter that he actually made a triangulation in the neighborhood of his home to measure the variation of the sum of the angles from the Euclidean estimate. We now know that this was a futile attempt because mensuration of terrestrial dimensions is Euclidean within experimental error. It is quite another thing when applied to the great distances of astronomical space.

Another curious example is related to the sum $1 + 1 = 2$. This identity is learned in childhood and we have an unreasoned belief in its universal applicability. And yet there is inferential reason to believe that the wave fronts of a spherical wave of light which depart in opposite directions from a lighted candle with the velocity of light are themselves separating with the velocity of light. Here we have the strange result that $c + c = c$, where c is the velocity of light. Georg Cantor, whose researches on the continuum has exerted so profound an influence upon the foundations of mathematics, invented a number to count the sequence of rational points. This number, alephzero, if added to itself, is still no greater than alephzero. Here again we have an example which violates the most fundamental identity in mathematics. After these difficulties had been explained to a certain class, one of the students expressed his profound thankfulness that he had never wasted much time upon a subject in which the founders did not appear to know what they were talking about. One did not dare to explain to him that this was, indeed, the basis of the definition of Bertrand Russell, who affirmed that "mathematics is the science in which we never know what we are talking about, nor whether what we say is true."

And so we reach the conclusion that the principle of logic merely affirms that when we have defined a set of postulates, and then have defined a set of operations, there are inevitable conclusions which may be obtained by operating with the defined operators upon those elements which satisfy the system of postulates. Each science as it reaches maturity attempts to reach this satisfactory logical formulation.

The second great principle of science is the *principle of determinism*. By this we mean that the elements of any science in its mature formulation are subject to laws which hold within determinate limits. Even probability has its laws of chance.

A measure of the deterministic structure of a science is the measure of the science. Thus, one understands from the astronomers that it is possible for them to mark upon the wall a small area and then affirm that 200 years from this very moment, if a telescope is pointed at that spot, the beams from the planet Jupiter will be shining down the barrel.

There is a story by O. Henry which relates the adventures of a young man upon the Road of Destiny. The young man comes to a place where the road branches. Then, said O. Henry, the young man took the left hand road. And down this road we follow him through a series of adventures at the end of which he is slain by an irate lover of the heroine. But fortunately, said the author, the story wasn't true. The young man took the right hand road. Alas, the story again has the same tragic ending. Well, said O. Henry, we can try again since the young man really took the central road. Again we follow him through a series of adventures and at the end he is finally slain under circumstances similar to those on the other roads. Hence there is a path of destiny and our lives, as all the other forms in the world of material things, are moved along this road by an immutable destiny.

Now science, consciously or unconsciously, has assumed a deterministic universe. Experiments performed at one time will yield the same results at another time within the limits of the probable errors. Planets move in their courses by the laws of an almost perfect mechanism and all science strives toward forecast. This is possible only under the postulate of determinism.

This postulate is accepted without reservations in some field of science, but perhaps with reservations in others which deal with the phenomena of life. There is at present a battle being waged between the proponents of the mathematical school of economics and those of the non-mathematical school on this very point. The mathematical school must inevitably contend that there are patterns of human conduct which repeat themselves under identical conditions. Deviations from these patterns are measurable again in terms of deviations from the assumed conditions. The apparent vagaries of human conduct may be traced to imperfections of measurement upon the one hand, and to the complexity of conditions which at all times prevail in the shifting patterns of economics, on the other.

An interesting example of this is found in the hedonistic concept of what Jevons has called *utility*, and Pareto *ophelimity*, that is to say, the measure of satisfaction. Your actions and mine are determined at all times by the relative ophelimites which we possess. Your pleasure in adding an increment of money to your wealth is proportional to the increment and inversely proportional to what you have. The coefficient in the ratio depends upon your personality, which may be generous, on the one hand, or miserly, on the other. There presumably exists an average value for this quantity. The question that must be answered, and which can be answered by inferential deductions, is whether or not the utility of money is of the assumed form. Many deterministic consequences depend upon this postulate.

The third great principle of science is the *extremum principle*. By this we mean that in many, if not all disciplines of science, there exists a fundamental quantity which nature either maximizes or minimizes. The most conspicuous example of this is the principle of least action, which even Einstein left inviolate in his restatement of some of the laws of physics.

The principle of least action has been employed so long as the basis of physics that there are perhaps many who have forgotten its strange metaphysical origin. Thus we find the following affirmation of Leonhard Euler, the father of most mathematical theories:

> As the construction of the universe is the most perfect possible, being the handiwork of an all-wise Maker, nothing can be met with in the world in which some maximal or minimal property is not displayed. There is, consequently, no doubt but that all the effects of the world can be derived by the method of maxima and minima from their final causes as well as from their efficient ones.

Strange as it may seem this is the metaphysical origin of that exemplary determinism of physics, as one may see from the words of Maupertuis who first stated explicity the principle of least action. Nature always minimizes action, which seems to us a much more remote concept than energy. Action is a function of four dimensions. A physical system always operates, says the principle, so that the integral of the space-time filament, multiplied by the differences between kinetic and potential energy, is a minimum. Why this strange behavior of nature? No one has yet given a satisfactory answer to the question and the pages of professional metaphysics do not reveal a more curious proposition among the philosophies.

Historically the principle may be regarded as having been a generalization of Fermat's theorem that light moves so as to minimize time of passage from one point to another. "Since nature performs her operations by the most direct routes or shortest paths, then the path of a ray of light between any two points must be such that the time occupied in the passage is a minimum."

The concept of entropy is in some respects stranger than that of action. Nature is always attempting to maximize this mysterious substance, which you will recall is the integral of an increment of heat divided by the absolute temperature. What mystery is here? Why should this curious entity play so fundamental a rôle in the theories of physics and chemistry? Why should it be the favored quantity, which nature attempts to maximize in all of its activities? But perhaps more interesting than these, is the question as to why the fatal maximum appears never to be attained. In this event, since entropy measures the available free energy in the universe, the stars would all be dark and the fatal "heat death" of Clausius would finally have been attained.

Let us turn for a moment to the social problem and the new developments in economics. There are those, stimulated by the success in other fields, who have asked the question: What does society, regarded from the point of view of economics, try to maximize in its manifold activities? Several answers have been given to this question, and as economics grows into a natural science its growth will be measured in terms of the validity of its answer to this question. There are those who say that profits must be maximized, or in more formal language, man behaves in such a way that he attempts to maximize the integral, taken between two dates, of the difference between net receipts from goods sold and the cost of manufacturing and selling these goods. There are many who decry the principle of maximum profits. It seems a sordid and egocentric maxim for mankind to follow. The collectivist theory would replace it by the principle of maximum production and maximum distribution of the things produced. Others would apply the doctrine of hedonism and maximize human satisfaction, measured, perhaps, by the utility function of Jevons or the ophelimity of Pareto. In this connection one may observe that there is a strange parallel between the definitions of entropy and the utility of money. In the first instance an increment of entropy is the increment of heat divided by the absolute temperature; in the second, an increment of money utility is the generosity coefficient times an increment of money, a kind of economic thermal unit, divided by one's absolute fortune.

The fourth great principle of science is the *principle of selection.* By this we mean that there exists in the objects of science certain mechanisms, which have the power of selection and choice. This class includes the class of living objects, but is broader than this class since it also includes such objects as crystals, whose mechanism of growth, mysterious in many ways as life, has also the power of environmental selection.

Under the coöperation of the biologists, we have often attempted the formulation of a system of postulates to define living things. To our astonishment there seems to be no way at present to define a categorical system of this kind. Any attribute, or collection of attributes, which is assumed as a postulates of life appears to be satisfied by equivalents from the chemical laboratory. A particularly clever biologist of my acquaintance delights in making synthetic plants. If there comes to him the suggestion of a new postulate he immediately creates a chemical mechanism which is isomorphic with the new attribute. When we were once examining one of these synthetic plants, which grew, adapted itself to its environment, developed a complex structure, budded and formed new plants, another colleague entered the laboratory. He examined our little plant, but could find no postulational reason for excluding it from the realm of living things. He finally said: "Although I cannot now tell you why, I know that this plant is not alive." But where was his assurance? Was it in a naïve faith in the existence of an entelechy, a power of selection, that transcended the mechanical powers of our little plant?

We shall not attempt a discussion of these enthralling matters here, but rather shall endeavor to show the relationship of the principle of selection to the other principles which have already been stated. The principle of selection is, in a certain sense, the antithesis of the concept of chance. The latter is a kind of negative proposition, which asserts that certain things will follow if random choices are made from a random chaos. The principle of selection, on the contrary, affirms that by its application, order can be obtained from chaos, and that the laws of chance can be violated by it.

For example, let four hands of bridge be dealt and spread before us. There we stand in the face of a remarkable event. Never before in the history of the world has that array of hands probably been seen nor is it likely that it will ever be seen again. The probability is approximately 1 in 54×10^{27}. But let us give the pack of cards to a child for him to play with. We shall not wait long before we see upon the floor a miracle. There before us will be the four perfect hands arranged in neat piles. The mechanism of selection has accomplished what chance could never do in centuries of time with millions of dealing mechanisms.

Let us look again at our law of entropy from the point of view of the principle of selection. The law of entropy in its most fundamental derivation flows out of the laws of chance. It is a kind of glorification of the theory of probability and rests upon the postulates of that noble science. One can prove by it that heat can never flow upstream against a gradiant of temperature.

But let us consider an example suggested by Clerk Maxwell. A box with two compartments A and B is filled with gas. In the compartment A the gas is hot, and in compartment B the gas is cold. A door between the two compartments is now opened and the hot gas mingles with the cold to form a mixture of average temperature. In the process entropy has been created and the free energy measured by the original differences of temperature has been lost forever. We are one step nearer the heat death of Clausius. But now let us introduce at the door between the two compartments a little demon, who has only one power, that of selection. A hot molecule in compartment B approaches the door and the demon allows it to pass into compartment A. Similarly a cold molecule approaches compartment B and is also allowed to pass. In this manner, merely by the principle of selection, compartment A is restored to its former temperature and compartment B to its former state of cold. The miracle of the ages has been performed. Heat has flowed uphill; the inviolate law of entropy has been violated; perpetual motion is a reality.

The rôle of the principle of selection is now apparent. It is the first element in the theory of evolution, a theory which violates the cardinal postulates of probability. An apple orchard, deserted by its cultivators, will soon revert to a wild state with sour and unpalatable fruit. Nature tends to level; a sort of biological entropy is at work. But let the selective principle again take hold of the orchard and it can be restored to its former state.

We have spoken before of the heat death of the universe, which must inevitably occur, but which never seems to be attained. And as we look into the depths of the sky we are struck by a strange thing. There, in certain places, we see vast red clouds of cosmic matter of unimaginable extent called the red giant stars such as Betelgeuse, Antares, Aldebaran, and the like. We know, as well as we can know anything in science, that these stars are but at the beginning of their life cycle. They will slowly decrease in size and by this contraction become hotter until ultimately they will be the most magnificent sights in the universe of stars. Then their energy will wane through the centuries; their magnificence will melt away, and they will finally disappear as insignificant red dwarfs, faint shadows of their former glory.

But the question that interests us here is, whence come these great giants, beginning their new life cycle? Do we see here a cosmic violation of the laws of entropy and is there somewhere in the remote regions of space a selective principle which provides the mechanism by which energy can be transformed into matter, and matter can again, under the influence of gravitation, melt away into radiant energy.

Before we discuss the concluding principle, the story of Micromegas, as related by Voltaire, must be told. Micromegas was an inhabitant of Sirius who once visited the earth. As he approached the earth he saw a vessel upon the surface of the ocean and approached it to ascertain the nature of the inhabitants of our planet. He found upon the vessel a group of philosophers, who were arguing together and who were holding their discussion in Greek. The subject of their debate was the soul. And this, said Voltaire, was altogether fitting since "we should quote what we do not comprehend in a language that we do not understand." The remainder of this address should be given in the Greek language.

The final principle of science we shall call the *transfinite principle*. This principle is different from the rest since it has never been formally presented, nor does it appear to have the same experimental validity as the other principles. It is found somewhat imperfectly implied in one of the last papers written by the German mathematician, David Hilbert in a discussion of the nature of "Infinity."

By the transfinite principle, we mean that the human spirit can add any transfinite postulates to any set of finite postulates and any deductions which result will be experimentally non-contradictory.

The first example to illustrate this point is taken from the writings of the illustrious astronomer De Sitter. As is known to many of you, De Sitter and Einstein disagreed in a very fundamental manner about the nature of the gravitational equations as they related to the universe as a whole. Einstein said that in very distant parts of the universe, remote from matter, space was flat. This meant in technical language that the matrix of the gravitational potentials became unity along the main diagonal and zero outside the diagonal. De Sitter, on the contrary, affirmed that in such distant regions real space disappeared altogether and hence that all the gravitational potentials were zero. Let us look at the exact words which he used:

"How the gravitational potentials are in those distant portions of space and time to which our observations have not yet penetrated, we do not know, and how they are at infinity of space and time we shall never know. All assumptions regarding the value of them at infinity are therefore extrapolations which we are free to choose in accordance with theoretical or philosophical requirements."

Now it happened that these two transfinite postulates had finite implications. Einstein's equations called for more matter than had yet been discovered in the universe. De Sitter's postulate required a shift of the spectrum of distant objects toward the red end of the spectrum.

Are we to believe that it was merely a coincidence that the nature of the spiral nebulas, vast collections of stars like our own galaxy, followed upon the heels of Einstein's assumption, or that the consequences of De Sitter's postulate has been amply verified by deeper and deeper penetrations into space? Remember that these consequences are deductions from mutually contradictory transfinite postulates.

An even more remarkable example from many points of view is the debate over the foundations of the quantum theory and wave mechanics. Here we find the strange anomaly that light behaves in one way as a wave and in another as a collection of particles of energy. Similarly, electrons have attributes of particles, but they may also be diffracted like waves. What a curious mystery is here, where mutually contradictory attributes are observed in the same entities!

In this instance the fact preceded the explanation, but the explanation is immediately seen to invoke the transfinite principle. Thus we observe that Heisenberg postulates a small rectangle of indeterminacy, wherein the laws of nature belong to a complete chaos. Within this rectangle we may make what laws we will and any assumption that has finite implications should be verified by experiment. Schrödinger's earlier explanation was of the same kind, except that he threw the anomalies upon infinity. The quantum theory is derived from the wave equations by assumptions affecting the *boundary conditions of the solutions at infinity.*

The three geometries with which we started are again explained by the transfinite principle. The sums of the angles of a triangle are determined by our judgments about the nature of parallel lines, which carry us into postulates about infinity. If we ask astronomers to tell us what is true, we find that they compute for us positive, zero and negative parallaxes of distant stars. These we recognize as coinciding with the parallaxes of the three geometries.

We have now surveyed some of the great principles upon which science rests: The principle of logic, the principle of determinism, the extremum principle, the principle of selection, and the transfinite principle. Within their scope a large part of science can find its origins and its aspirations.

In conclusion it might be well to state the scientist's personal creed, or at any rate, a creed which represents the highest goal of the scientist himself. This statement is taken from Henri Poincaré:

> The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful. If nature were not beautiful, it would not be worth knowing, and if nature were not worth knowing, life would not be worth living. Of course I do not here speak of that beauty which strikes the senses, the beauty of qualities and of appearance; not that I undervalue such beauty, far from it, but it has nothing to do with science; I mean that profounder beauty which comes from the harmonious order of the parts, and which a pure intelligence can grasp. This it is which gives body, a structure so to speak, to the iridescent appearances which flatter our senses and without this support the beauty of these fugitive dreams would be only imperfect, because it would be vague and always fleeting. On the contrary, intellectual beauty is sufficient unto itself, and it is for its sake, more perhaps than for the future good of humanity, that the scientist devotes himself to long and difficult labors.

NORTHWESTERN UNIVERSITY,
EVANSTON, ILLINOIS.